Conceptual Design and Feasibility Analyses of Robotic System for Automated Pigging Operation

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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ABSTRACT

Pigging technology discovered and developed originally by the oil industry more than 100 years ago (G. Hiltscher, 2003) . The term pigging is primarily associated with cleaning. However pigging is more than that as numerous other field have been develop for pigging. Pigs can inspect, detect, measure and check. In many applications, pigging has become indispensible; in sterile and food technologies, pipeline industry, and oil and gas industry.

Currently in oil and gas industry, launching and receiving of pigs are time consuming and both human and mechanically inefficient. Pipe pigging techniques for the internal cleaning and/or coating of pipelines, are summarized as follows: Pigs are devices which are launched from one end of the pipeline, and caught at the other end in a receiver "trap". The pigs can be propelled by a variety of means, such as compressed air, water and even the process liquid in the pipeline (Louis Pretorius Corrocoat SA Ltd., 2006)

Maintenance cleaning and smart pigging of selected line have become necessary and manually operated. The objective of this project is to design a pig launcher robot that can assist in pig launching task which requires no human intervention and reduce operation time during pigging process.

ACKNOWLEDGEMENT

First and foremost, I give thanks and praise to God for His guidance and blessings throughout the entire course of my Final Year Project. I wish to express my gratitude to Mrs Rosmawati Bt. Mat Zain, for her guidance and support throughout completing my Final Year Project as partial fulfillment of the requirement for the Bachelor of Engineering (Hons) of Mechanical Engineering. I received an immeasurable amount of guidance, ideas, assistance, support and advice from various figures. Without their help, this Final Year Project may not have been successful. Here I express my greatest appreciation to Universiti Teknologi PETRONAS, especially the Mechanical Engineering Department for giving me the opportunity to embark on this project in which has equipped students with essential skills for self-learning. Finally, I would like to thank my family for they have been a wonderful source of encouragement and joy to me and not to forget as well my fellow colleagues which gave their effort in ensuring the smooth completion of this project. Their help was a tremendous gift to me. May God bless all of them, as only HE, the Almighty could recompense them for their goodwill.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Pigging operation refers to the practice of using pipeline inspection gauges or 'pigs' to perform various maintenance operations on a pipeline. Nowadays, pigging operation is an important routine for pipeline especially in oil and gas industry.

1.2 PROBLEM STATEMENT

Throughout the years many accidents happened all over the world during loading and offloading the pig in pigging operation since there is manual labour involved. Receiving or launching the pig involves a number of sequential valve operations in combination with opening and closing the closure door. One mistake in this operation could easily cause severe injury, even death, to the operator or a bystander. With the main driver of reducing the HSE risks in sour gas facilities, ABB and Shell have collaborated in scraper handling robot for pigging operation (David A. Anisi, 2010). But there are limitation imposed by the project which is only handling the pig and not the whole pigging operation. Thus, this research is to automate the whole pig launcher operation including valve operation.

1.3 OBJECTIVE

The main objectives of this study are:

i. To come out with conceptual design of robotic arm to facilitate an automated pig launcher operation.
ii. To analyse all the conceptual design and come out with a comparative study.

1.4 SCOPE OF STUDY

The scope of this project can be divided into literature review, conceptual design, simulation and analysis.

1.4.1 Literature review

This stage is basically desk study. These involve a thorough study of pipeline pigging operation and the research of the existing method and technology of pig launching.

1.4.2 Conceptual design

The design of automated pig launcher robot system will start after the basic requirements are understood.

1.4.3 Simulation

Simulation will be conduct to choose the best automated pig launcher robot system. This is the most critical part of the project. Thus it is essential to obtain all necessary information of the pigging equipment used especially in pig launcher station.

1.4.4 Analysis

Quantitative and qualitative analysis will be generated as an analysis result.

CHAPTER 2
LITERATURE REVIEW

2.1 PIPELINE PIGGING

The term "pigging" originated in the gas and oil industry, where metal discs connected by a rod were moved through the oil pipelines to remove build up of paraffin wax on the internal wall of the pipe (G. Hiltscher, 2003). The action of metal on metal made a squealing noise like a pig and the name stuck.

Pigging is used to describe a mechanical method of displacing a liquid in a pipeline or to clean accumulated paraffin from the interior of the pipeline by using a mechanized plunger or "pig." Paraffin is a waxy substance associated with some types of liquid hydrocarbon production. The physical properties of paraffin are dependent on the composition of the associated crude oil, and temperature and pressure. At atmospheric pressure, paraffin is typically a semi-solid at temperatures above about 100 ^{o} F and will solidify at about 50 ^{o} F. Paraffin deposits will form inside pipelines that transport liquid hydrocarbons and, if some remedial action, such as pigging, is not taken, the deposited paraffin will eventually completely block all fluid flow through the line.

The pigging method involves moving a pipeline pig through the pipeline to be cleaned. Pipeline pigs are available in various shapes and are made of various materials, depending on the pigging task to be accomplished. A pipeline pig can be a disc or a spherical or cylindrical device made of a flexible material such as neoprene rubber and having an outside diameter nearly equal to the inside diameter of the pipeline to be cleaned. The movement of the pig through the pipeline is accomplished by applying pressure from gas or a liquid such as oil or water to the back or upstream end of the pig. The pig fits inside the pipe closely enough to form a seal against the applied pressure. The applied pressure then causes the pig to move forward through the pipe.

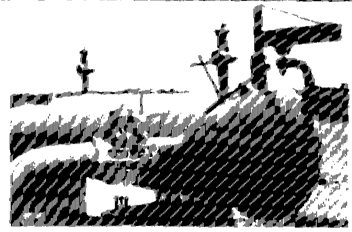
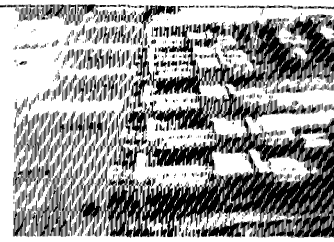
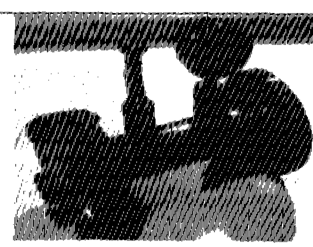
As the pig travels through the pipe, it scrapes the inside of the pipe and sweeps any accumulated contaminants or liquids ahead of it. Routine pigging will be required of oil sale lines at frequencies determined by production rates and operating temperatures. The frequency of pigging could range from several times a week to monthly or longer, depending on the nature of the produced fluid.

The pigging process has 4 stages (D.R Shannon):

- ***Mechanical scouring*** by a variety of different scraper pigs, such as types with hardened studs or screws to loosen debris and corrosion products and even tungsten steel de-scaling pigs used to break up hard sediment or hard corrosion deposits.
- ***Mechanical cleaning*** of the pipeline using foam swabs, a variety of different wire brush scraper pigs, and various urethane blade scrapers to remove all deposits including debris, corrosion products and sediment.
- ***Chemical cleaning*** and chemical treatment of the pipe surface, using pairs of squeegee pigs or wiper tools, to ensure a clean, dry metal finish, including acid etching and corrosion inhibition surface treatment as part of the surface preparation.
- ***Coating Application*** pigs used to screed apply various coating polymers using specially designed flexible application pigs. These coating pigs are batched between screeding tools and make several runs, ensuring a multi-layer, continuous lining of the specified thickness, along the complete length of the pipeline.

The first step in the process is that remote mechanical scraper pigs are launched into the pipeline. Scrapers remove the corrosion and deposit build up in the pipes, which results in an increase in flow through the pipeline. After mechanical cleaning, intelligent pigs can be run for pipeline assessment, or the pipeline can be further cleaned in preparation for coating. Chemical cleaning involves repeated runs with detergents, solvents, and acids. When the pipeline is thoroughly clean internally, it is ready to be coated with a seamless internal liquid applied lining.

2.2 EQUIPMENT REQUIREMENTS IN PIGGING OPERATION (Tiratsoo, 2003)

No	Equipment	Function	
1.	Launcher and receiver	• Designed for the introduction and removal of various types and sizes of PIGS within a pipeline system. • Equipped with quick opening closures	 Fig 1: Pig Launcher (Beamer & Associates LLC)
2.	Pig signaler	• Fitted to launcher and receiver units to confirm the launch / arrival of a pig. • Can also be at any location along the pipeline length to give indication of a pig at a specific location.	 Fig 2: Pig Signaler (Beamer & Associates LLC)
3.	Volume and pressure regulator	For regulation of pressure and pig velocity in transfer lines	 Fig 3: Volume & Pressure Regulator (Beamer & Associates LLC)
4.	Pressure gauge	Indication of line pressure or pigging-air supply pressure.	 Fig 4: Pressure Gauge (Beamer & Associates LLC)
5.	Pressure	To record operating pressure	

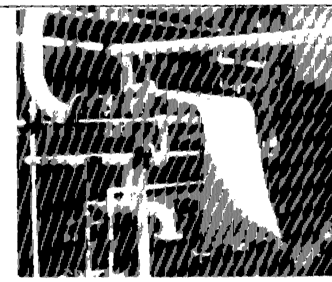
	recorder	reading and normal pigging pressure reading so that if abnormalities occur, a comparison chart is available to indicate where the possible problem is in the pipeline.	
6.	Disposal	To collect waste or by-product from pigging operation Example: dust bag	 Fig 5: Disposal Bag (Beamer & Associates LLC)

Table 1: Pigging Operation Equipment

2.3 GENERAL PROCEDURE OF PIGGING OPERATION

(MacDonald, 2010)

The pigging operation involves the cleaning, inspection and integrity check (such as checking of gas pipe's wall thickness) of the pipelines. This kind of inspection method is so far the most reliable and comprehensive one for pipelines. Here are the general procedures to describe the pigging operation:

i. Inert gas (Nitrogen) is injected into the pig launcher after confirmation of closing the isolation valve of the pig launcher to remove any residual town gas inside the pig launcher. This step is to verify that the trap is depressurized.

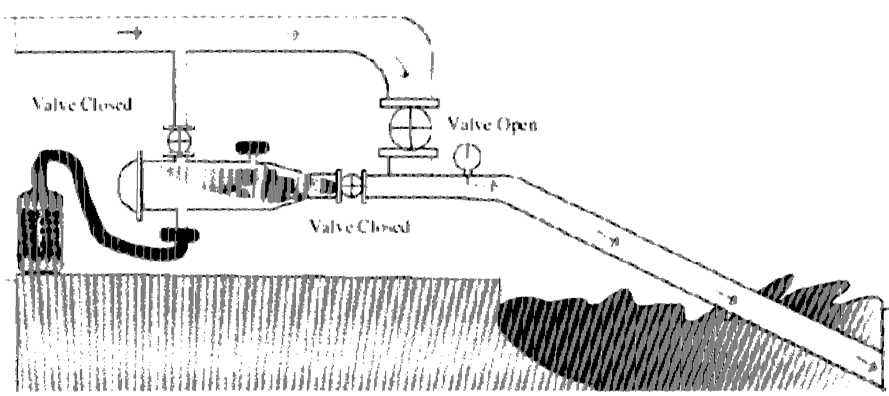


Fig 6: Pig Launcher Depressurize

ii. Upon the pig launcher is depressurized; the pig launcher is opened up. Pipe Inspection Gauge (pig) is then inserted into the pig launcher.

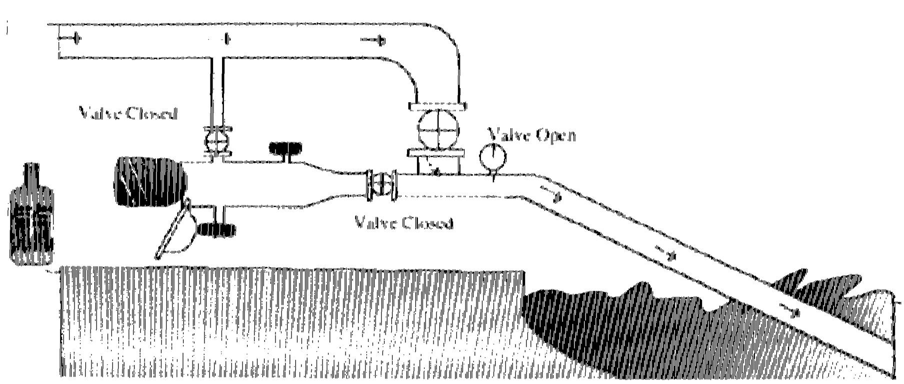


Fig 7: Pig Insertion

iii. After insertion of the pig into the launcher, close the door of the pig launcher and then purge the pig launcher with inert gas. The isolation valve for the pig launcher and behind the pig is opened and the pig launcher will then fill up with town gas. The town gas flow will carry the pig to pass through pipelines to the pig receiver station.

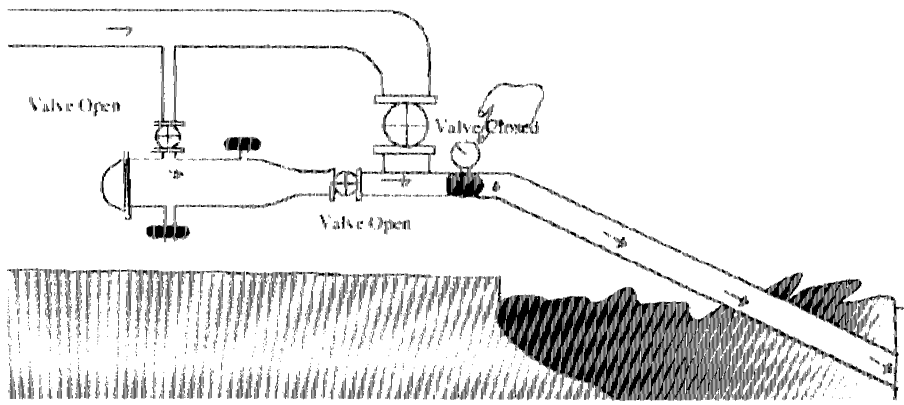


Fig 8: Valve Operation upon Pig Launching

iv. Pig arrives at the other end of gas pipeline at where a pigging station is designed for receiving the pig.

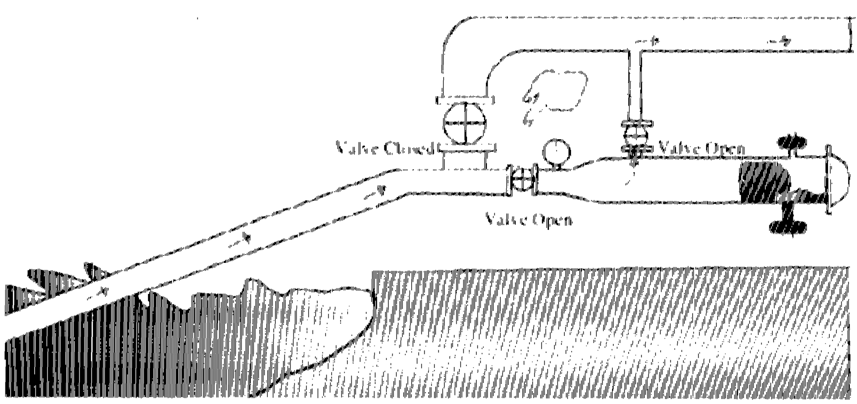


Fig 9: Pig Receiving

v. Inert gas (Nitrogen) is injected into the pig receiver after confirmation of closing the isolation valve of the pig receiver to remove any residual gas inside the pig launcher. This step is to verify that the trap is depressurized.

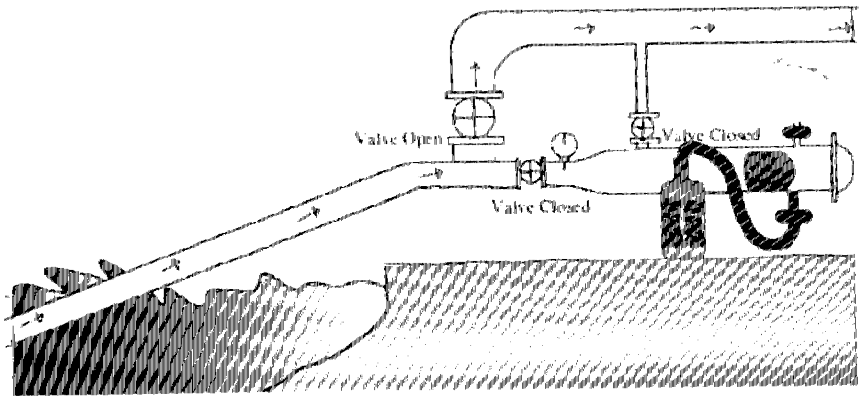


Fig 10: Pig Receiver Depressurize

vi. Upon the pig receiver is depressurized; the pig receiver is opened up. Pig is then taken out from the pig receiver.

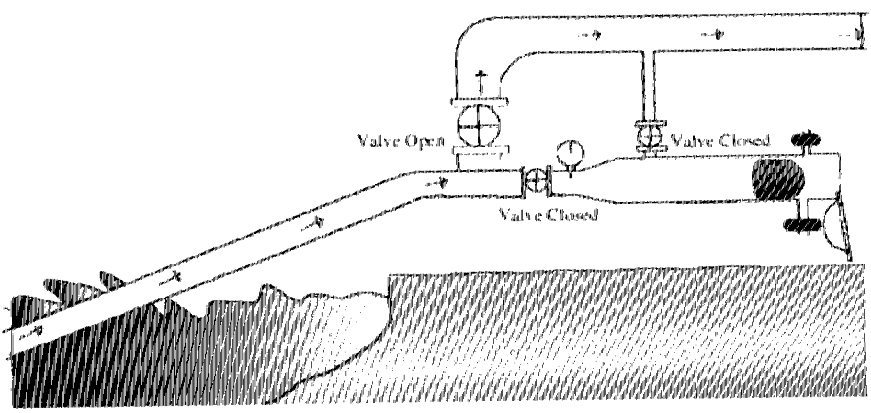


Fig 11: Opening of Receiver Door Closure

vii. All the isolation valves are then closed. The pipe receiver will be isolated from the main gas pipeline during normal situation.

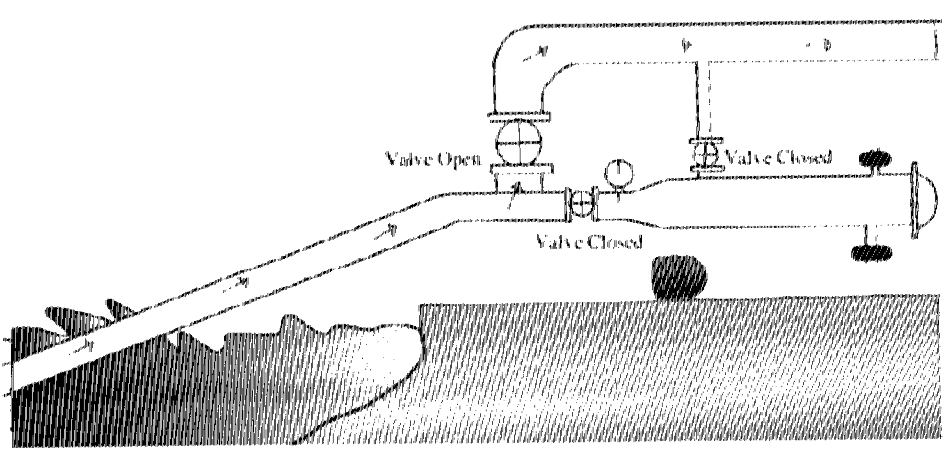


Fig 12: Pig Retrieval

2.4 TYPICAL PIG LAUNCHING PROCEDURE (Girard)

The operational sequence described below is for general pig launching procedures that can be used as a guideline.

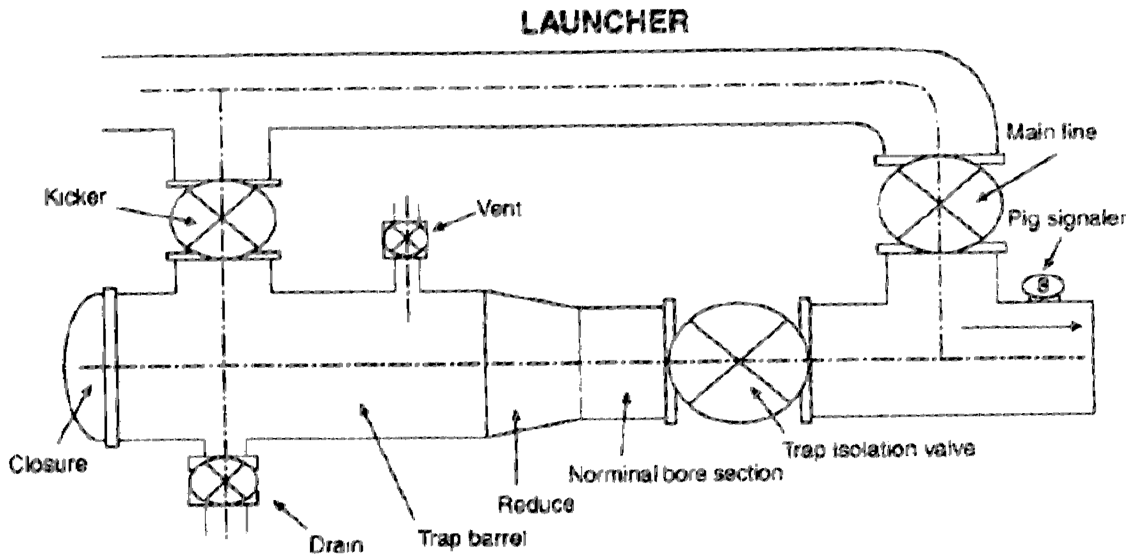


Figure 13: Pig Launcher Configuration

i. Make sure that the isolation valve and the kicker valve are closed.

ii. In liquid systems, open the drain valve and allow air to displace the liquid by opening the vent valve. In natural gas systems, open the vent and vent the launcher to atmospheric pressure.

iii. When the pig launcher is completely drained (0 psi), with the vent and drain valves still open; open the trap (closure) door.

iv. Install the pig with the nose firmly in contact with the reducer between the barrel and the nominal bore section of the launcher.

v. Clean the closure seal and other sealing surfaces lubricate if necessary and close and secure the closure door.

vi. Close the drain valve. Slowly fill the trap by gradually opening the kicker valve and venting through the vent valve.

vii. When filling is complete, close the vent valve to allow pressure to equalize across the isolation valve.

viii. Open the isolation valve. The pig is ready for launching.

ix. Partially close the main line valve. This will increase the flow through the kicker valve and behind the pig. Continue to close the main line valve until the pig leaves the trap into the main line as indicated by the pig signaler.

x. After the pig leaves the trap and enters the main line, fully open the main line valve. Close the isolation valve and the kicker valve.

xi. The pig launching is complete.

2.5 CURRENT PIG HANDLING OPERATION (PTS20.200, 1994)

The requirements for pig handling depend on the type and weight of pig and the pipeline size: normal pigs with a mass less than 45 kg may be manually loaded into or out of the pig traps. Equipment such as tables (troughs) combined with hydraulic rams/winches or elevating trolleys is use to assist with local pig handling where platform cranes cannot be readily made use of to assist with handling operations. Trolleys are equipped with a raise/lower mechanism, insertion/ extraction winch and wheels suitable for maneuvering on deck grating. Two of the wheels should be free to pivot in any direction to enable the trolley to be maneuvered in small areas. If the launcher / receiver is not on the top deck or if pigs cannot be readily transferred by handling trolley to a crane access point, a deck extension for crane access at or adjacent to the pig handling area is used.

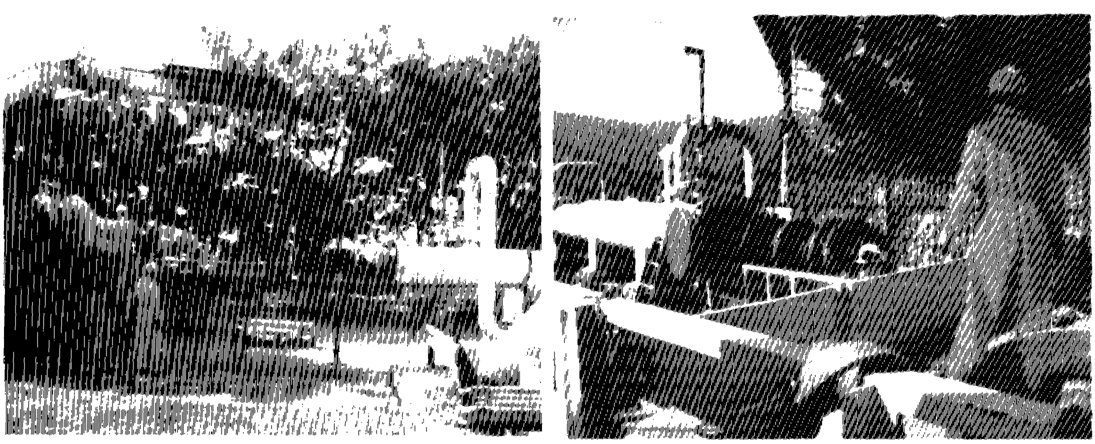


Fig 14: Installation of Pig during Pigging Operation (David A. Anisi, 2010)

2.6 ISSUE IN PIGGING OPERATION

The use of pig launcher and receiver stations for pipeline cleaning, inspecting and maintenance is a method seen worldwide. The main benefit of this type of maintenance is that is can be carried out without interrupting the process in operation. The disadvantage is that it is also a high risk event.

A launcher or receiver station is typically a vessel connected in parallel to the existing pipeline. This makes it possible to launch or receive the pig using the pipeline's normal operating pressure and without interrupting the flow or stopping production. The vessel is equipped with a closure door to load or offload a pig. By leading the process through the launcher station, the pig will be launched and pushed through the pipeline to be received at the other end in the receiver station.

The method currently used in pipeline industry to insert and remove the pig is only by human force with the aid of chain block. Up to four men have to handle the operation and this operation lasts up to four hours.

Throughout the years many accidents happened all over the world during this dangerous maintenance operation since there is manual labour involved in loading and offloading the pig. According to statistics, "70% of the reported incidents in the oil and gas industry worldwide are attributable by human error" (Smith). Here are few incidents recorded:

i. *United States Department Of The Interior Minerals Management Service Gulf Of Mexico Region Accident Investigation Report (refer appendix 1)*

   On October 23, 2008, at approximately 1730 hrs, a Lead Operator (LO) sustained a break to his right arm just above his wrist during a pipeline pigging operation.

ii. *Canada National Energy Board Safety Advisory NEB SA 2007-01 (refer appendix 2)*

   At approximately 5:15 p.m. on November 23, 2006, during planned work related to an internal inspection project, two batch pigs were ejected under pressure from the barrel of a 14" temporary receiving trap striking and seriously injuring two workers.

People can be trained to follow procedures and informed about potential danger but a mistake cannot be excluded.

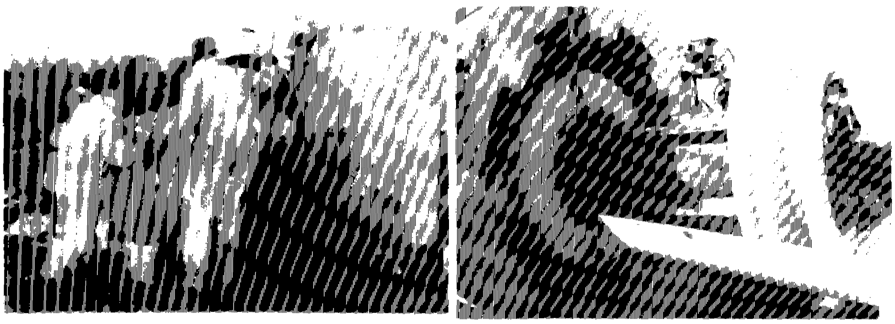


Fig 15: Pig Launching (D.R Shannon)

Fig 16: Pig Retrieve (Pigtek Ltd)

Receiving or launching the pig involves a number of sequential valve operations in combination with opening and closing the closure door. One mistake in this operation could easily cause severe injury, even death, to the operator or a bystander. Several safety measures such as written procedures and safe operating practice available but this is no guarantee that all of the above is taken into consideration. Accidents in pigging operation appear to fall into three main areas.

i. ***Handling pressurized equipment*** (Tiratsoo, 2003)

   Routine pigging operations involve exposure to equipment normally operating at high pressure and possibly containing fluids which are either flammable or toxic.

ii. ***Loading and unloading of pigs*** (Tiratsoo, 2003)

   One of the major safety areas in pigging is the mechanical loading of pigs into launcher and unloading of pigs from receivers. Usually it relates to the launcher/receiver not being properly de-pressured. With pressure built in front, the pig prematurely ejected backwards and with pressure built behind the pig, it launch like a cannon out the end of the receiver when operator opens the hatch.

iii. ***Defective equipment*** (cheresource.com)

These are example of defective equipment event that leads to pig premature ejection as a result of pressurize launcher/receiver.

- Vent/ drain valves are prone to plugging. These are often small valves and can be plugged because of the dirty material that has been scraped from the pipeline by the pig.
- The pig could be stuck, if there is a restriction, upstream of the vent valve there could be a trapped pocket of high pressure gas.
- The pressure gauges are often scaled to pipeline pressure which could be 1000 psig. Even relatively low pressure (20 psig) can launch the pig and cause serious injury. These low pressures cannot be accurately read on most standard gauges (scaled for high pressure).

2.7 AUTOMATION CONCERN FACTOR

For automation needs concerns, author has developed five major factors which motivate automation development. They are safety, productivity, worker utilization, superhuman handling and quality (Guo, 1993). All these factors are further divided into several sub factors.

Safety concerns arise from the high accident rate of the pigging operation. Thus, any task involving a safety concern should be considered for automation. Hazardous to health, physical dangerous, and elevated work are sub-factors defined in this concern. The productivity concern involves aspects such as repetitive, dirty or unpleasant, boring, tedious, and exhaustive work. The manufacturing industry has utilized many robot applications to improve human productivity. Pigging tasks with similar natures undoubtedly will gain essential productivity improvement if automation development can be applied.

The worker utilization concern deals with the supply and skill level of human labour. Special skill requirements and labour intensive are the sub-factors in this category. The super-human handling concern implies tasks which are not appropriate for human workers to handle. For tasks where the requirements exceed the physical capabilities of human labour, some kind of equipment or automation device will be needed to assist in completing the task. Heavy lift, high lift and careful tasks are typical cases in this category.

The quality concern considers both the tolerance level and consistency requirement of a pigging operation. Automation development is expected to relieve this problem by achieving a better working quality through the use of machines. Therefore an automated pigging operation system development is crucial. Pig launcher robot is to be developed to facilitate automated pigging operation which can reduce safety issue by eliminate operator onsite.

CHAPTER 3

METHODOLOGY

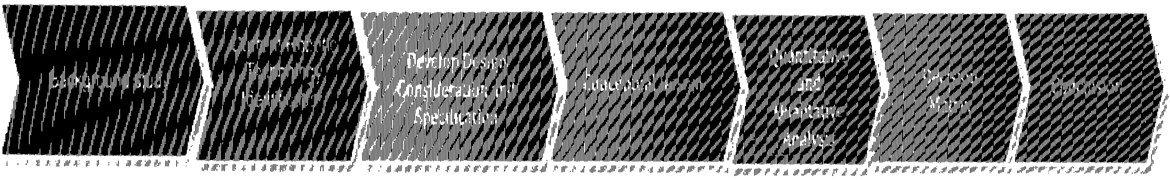


Fig 17: Study Flow Diagram

i. ***Background study:***

Background study include general operation and procedure of pigging operation, issues in pigging operation which specifically HSE and automation concern factor.

ii. ***Current Robotic Technology Identification:***

Robotic technologies in three difference field have been taken as reference which are industrial robot, oil and gas field robot, and aerospace robot. Detail is discussed in section 3.1.

iii. ***Develop design consideration and specification:***

Major consideration and specification for the design are stated in section 3.2.

iv. ***Conceptual design:***

Three conceptual design are develop based on the design consideration and current technology available study. Detail in section 4.1.

v. ***Quantitative and qualitative analysis:***

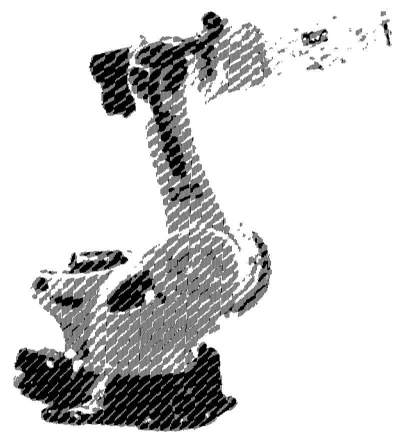
Analyse the applicability of the three conceptual ideas using workspace analysis and analytical hierarchy process (AHP). Detail in section 4.4 and 4.5.

vi. ***Decision matrix:***

Decision matrix has been chosen by author as a decision making tool to select the best alternative. Detail in section 4.6.

3.1 ROBOTIC TECHNOLOGY IDENTIFICATION

Existing technology available may be applied or adapt for pig launcher robot. Basically automated pigging operation involve task such as pick a pig, load into trap and turning valve manipulator tool. Available industrial manipulators seem an alternative as they capable to execute those tasks. Industrial robots are found in a variety of locations including the automobile and manufacturing industries. Typical industrial robots do jobs that are difficult, dangerous or dull such as lift heavy objects, paint, handle chemicals, and perform assembly work. Outside the manufacturing world, robot can be found in hazardous duty service, maintenance jobs, fighting fires, medical applications, military warfare and on the farm. Table 2 layout several robot from existing industrial and other field that have been taken as reference of the develop pig launcher robot.

No.	Robot	
1.	**Material handling robot in manufacturing** • Material handling is the broadest category of applications that involves moving, selecting or packing products. • Material handling robots are used to move, feed or disengage parts or tools to or from a location, or to transfer parts from one machine to another. • Material handling automation can create a safer working environment by removing operator from potentially dangerous pig loading task. • Example of material handling robot: KUKA KR 1000 TITAN F (KUKA Industrial robot) The KR 1000 titan is the right choice when it comes to bridging distances of up to 6.5 m and ensuring precise handling of engine blocks, stone, glass, steel sections, components for ships and aircraft, marble blocks, precast concrete parts and much more.	 Fig 18: KUKA KR 1000 Titan F (KUKA Industrial robot)
2.	**ABB IRB5500 scrapper handling robot** (David A. Anisi, 2010) • Collaboration of ABB and Shell to reduce HSE risk in pigging operation. • The robot has been equipped with a tool	

specifically designed for scraper handling.

- The robot only handles pig loading and offloading.
- The tool includes sensors to guide the robot and to verify that operations can be performed safely.
- The robot has been controlled by an operator interface next to the robot.
- Robot was powered with a standalone diesel generator and produced its own instrument air

Steps in scrapper handling task perform by ABB IRB5500 robot:

i. The robot is first verify door lock and handle are in the expected locations (locked and closed). This is done using a proximity switch integrated into the tool.

ii. The robot unlocks and opens the barrel door to allow debris and residue oil to pour onto a drain table in front of the barrel.

iii. The robot inserts the tool into the barrel and searches for the scraper. The tool compromises a proximity switch that indicates the presence of a scraper in front of the tool. The search is performed with inbuilt functionality in the robot controller to stop the movement on state change of an input signal.

iv. When the scraper is found, the robot

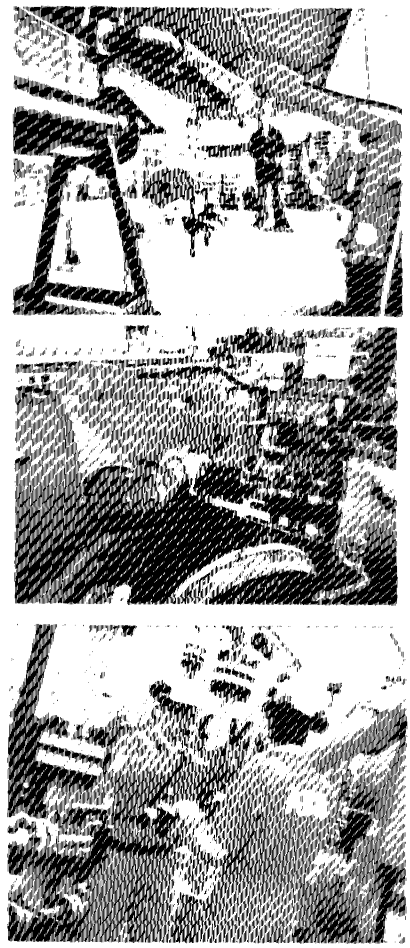


Fig 19: ABB IRB5500 Onsite Demonstration (Terwiesch, 2011)

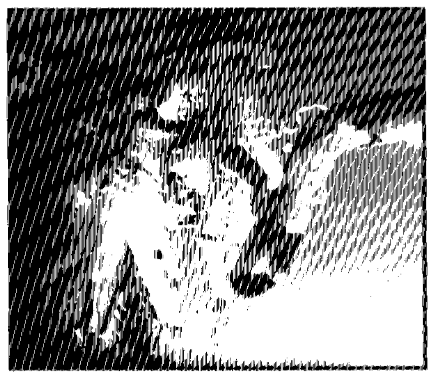
	extracts the scraper and places it on the table. v. The door is then closed and locked before the robot returns to its home position.	
3.	**Aerospace Remote Manipulator System (RMS)** (prime.jsc.nasa.gov) • RMS is electromechanical arm that maneuvers a payload from the payload bay of the space shuttle orbiter to its deployment position and then releases it. • The RMS has six joints that correspond roughly to the joints of the human arm, with shoulder yaw and pitch joints; an elbow pitch joint; and wrist pitch, yaw and roll joints. The end effector is the unit at the end of the wrist that actually grabs, or grapples, the payload. • The RMS is capable of deploying or retrieving payloads weighing up to 65,000 pounds. The RMS can also retrieve, repair and deploy satellites.	 Fig 20: Aerospace Remote Manipulator System (RMS) (prime.jsc.nasa.gov)

Table 2: Existing Robotic Technology

3.2 MAJOR CONSIDERATION FOR THE DEVELOPMENT OF PIG LAUNCHER ROBOT

The pig launcher robot proposed in this study should be applicable to the existing pig launcher station at petroleum refinery plant. In this study, the general considerations required for the development of the pig launcher robot were mainly derived from pigging operation sequence where there are steps that must be followed. Receiving or launching the pig involves a number of sequential valve operations in combination with opening and closing the closure door. In this study, detailed analysis of pig launcher equipments, pig launcher station layout and operation sequence was performed in an effort to derive a design concept for easy installation and movement of the robot at pig launcher station.

3.2.1 General consideration

Following are the general consideration required for development of pig launcher robot:

- Typically there are five valves (namely kicker, vent, drain, trap isolation and main) and a closure that need to be operated by the pig launcher robot upon pigging operation. Thus a pig launcher robot should be design to have quick and easy access to all valves and door closure.

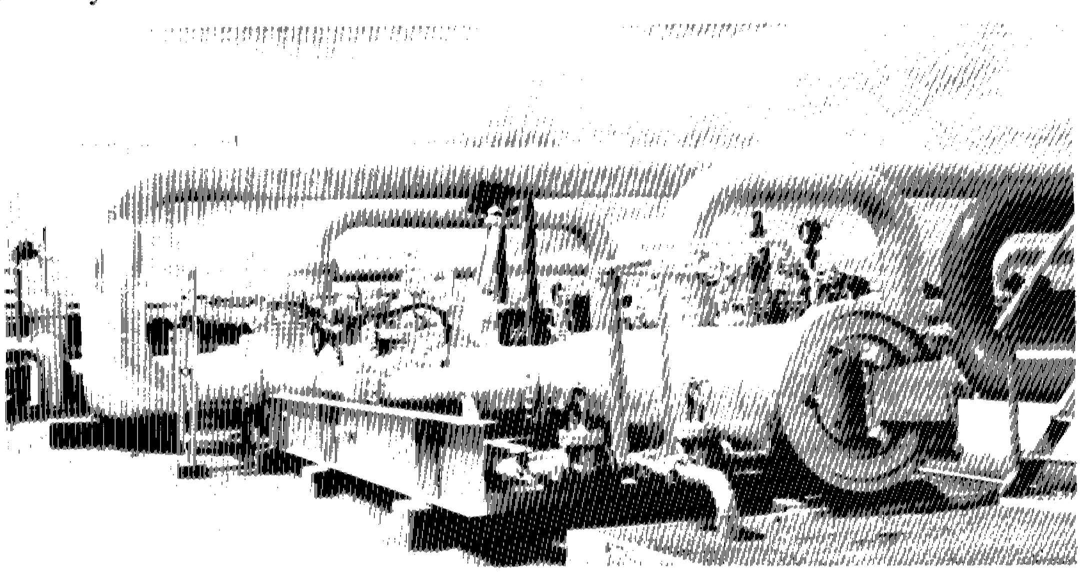


Figure 21: Pig Launching Station

- How to avoid major modification to the plant system. Pig launcher robot is a mass robot system which need power generator and pneumatic or hydraulic supply. Thus consideration to provide standalone power generator and instrument air is needed.
- How the design robot can execute task precisely. Precisely define by successful of robot arm to open or close valve because it based on orientation of valve manipulator. Besides, loading pig into trap need a precise execution.
- Even on the same pig launcher station, the valve may be partly different especially the size. Therefore the pig launcher robot should be design to flexibly cope with such varying size of valves.
- The robot must comply with ATEX standard[1].

[1] The abbreviation derives from the French title: Appareils destinés à êtreutilisés en ATmosphères EXplosibles.

3.2.2 Specification used for robot design:

i. *Open pigging system* (G. Hiltscher, 2003, p. 10)

In an open pigging system the pig can travel through the pipe only in one direction. At receiving station, the pig is removed and returned externally to the launching station.

ii. *One pigging system* (G. Hiltscher, 2003, p. 11)

Only one pig is launch for the operation.

iii. *Horizontal launcher*

iv. *Use standard pig trap* (PTS31.40.10, 1998)

Comply with PETRONAS Technical Standard: Design of Pipeline Pig Trap System

v. *Pipeline diameter is 10 inch*

vi. *Pig weight is 10.4 kg* (PTS31.40.10, 1998)

3.3 THE DEVELOPMENT SYSTEM

A robotic system generally comprises many modules that need to work together to perform a task. The required capability range of robots for hazardous environment is very wide depending upon factors such as the nature of the task, the degree of structure in the environment and the level of hazards.

Based on pig launcher procedures and steps, the important functional element of pig launcher robot is articulated/manipulator arm which is critical in opening and closing of valves, running drain pumps and removing vent plugs. Existing industrial robotic arm available in the market nowadays is perfect for the pig launching task execution. The majority of current automated systems employ virtually no autonomy or even programmed motion. ABB IRB5500 industrial robot which has been used in ABB-Shell scrapper handling demonstration is taken as reference pig handling robot.
This robot consists six degree of freedom manipulator, hydraulic tank, controller and remote-control device. It can be mounted on wall or floor. The robot has been equipped with a tool specifically designed for up to 13kg scraper handling. The tool includes sensors to guide the robot and to verify that operations can be performed safely.

3.3.1 **ABB IRB 5500** (ABB IRB5500 datasheet, 2009)

An ATEX certified industrial ABB robot (IRB5500) has been used for ABB-Shell scrapper handler robot demonstration.

Specification

Number of axes: 6 axes

Payload on wrist: 13 kg

Reach of handling: 5.8 m

Physical

Robot mounting: Wall, floor, tilted, inverted

Robot footprint: 500 x 680 mm

Robot unit weight: 540 kg

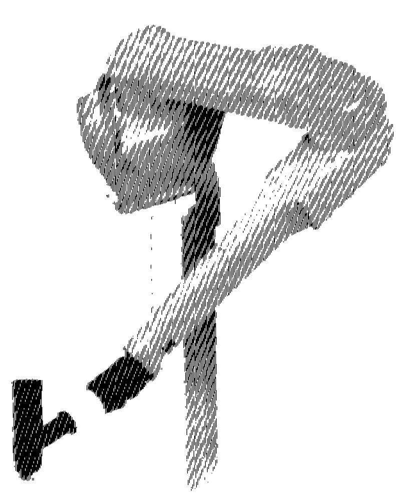


Fig 22: ABB IRB5500

Performance (Velocity maximum speed)

Axis 1, 2 and 3 100°/s

Axis 4 - Wrist rotation 465°/s

Axis 5 - Wrist bend 350°/s

Axis 6 - Wrist flange rotation 535°/s

Wrist work envelope ±140°

Environment

Ambient temperature: Manipulator 0 – 40°C

Relative humidity: 95% Max

Degree of protection: IP67 (wrist IP54)

Workspace Envelope

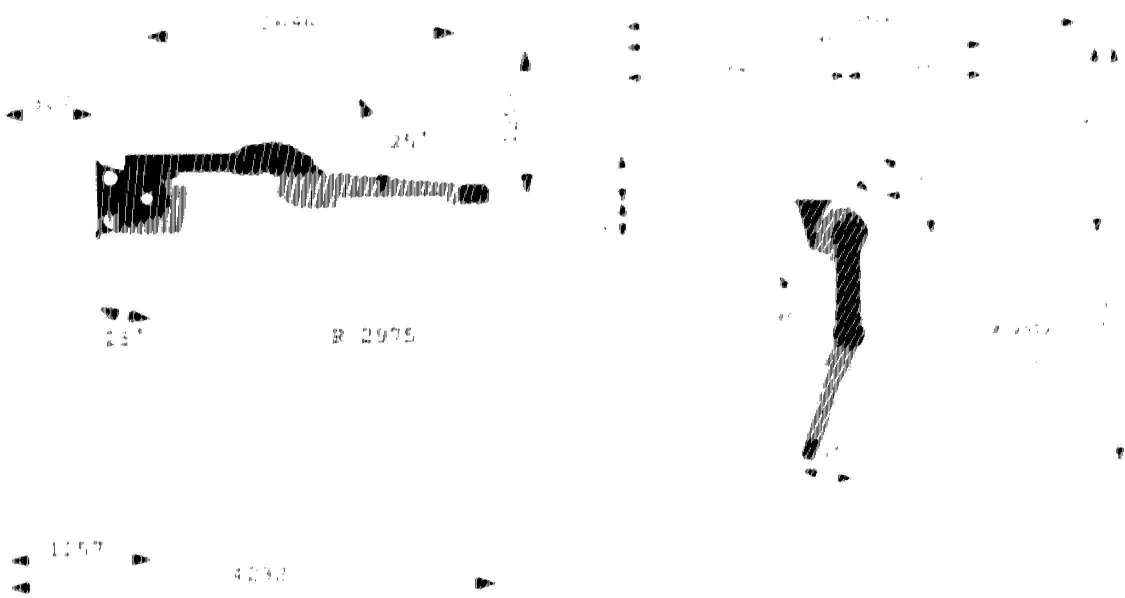


Figure 23: ABB IRB5500 Workspace

CHAPTER 4
RESULTS AND DISCUSSION

4.1 CONCEPTUAL DESIGN

In this study, three conceptual ideas stand-alone, rail-guided and multiple robot configurations have been suggested based on accessibility of robot with pig launcher equipments (valves, door and etc) at launching station to automate all task in pig launching operation.

4.1.1 Stand alone robot configuration

In this configuration, ABB IRB5500 robotic arm has access to all valves and door closure. Thus it has to be located on a position which allows maximum access to all valves.

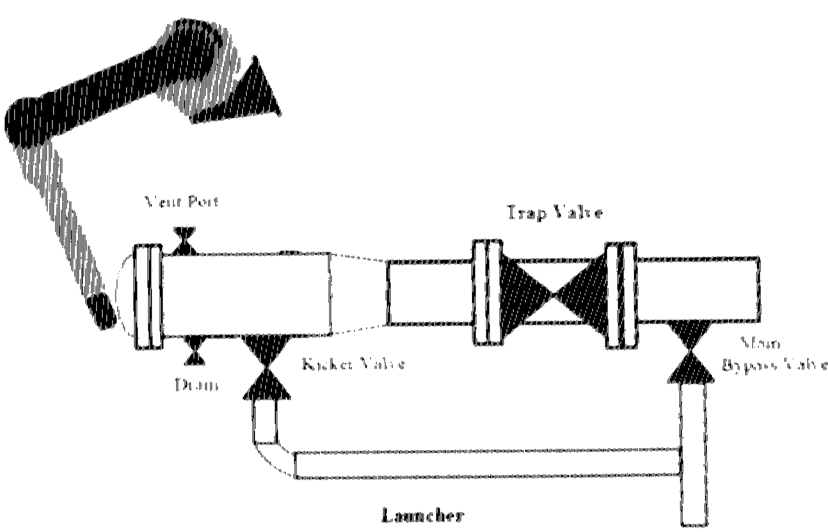


Figure 24: Stand Alone Robot Configuration

Other alternative for this configuration is an automated system can be installed on the valve using the current technology that has been applied for subsea system. Gate valves are used and drive by hydraulic operated actuator which control by operator in control room. The pig launcher control system will interface the control system using standard communications interface. It will use the existing infrastructure for communication and power as the subsea system. If not, operator needs to assist the valve operation.

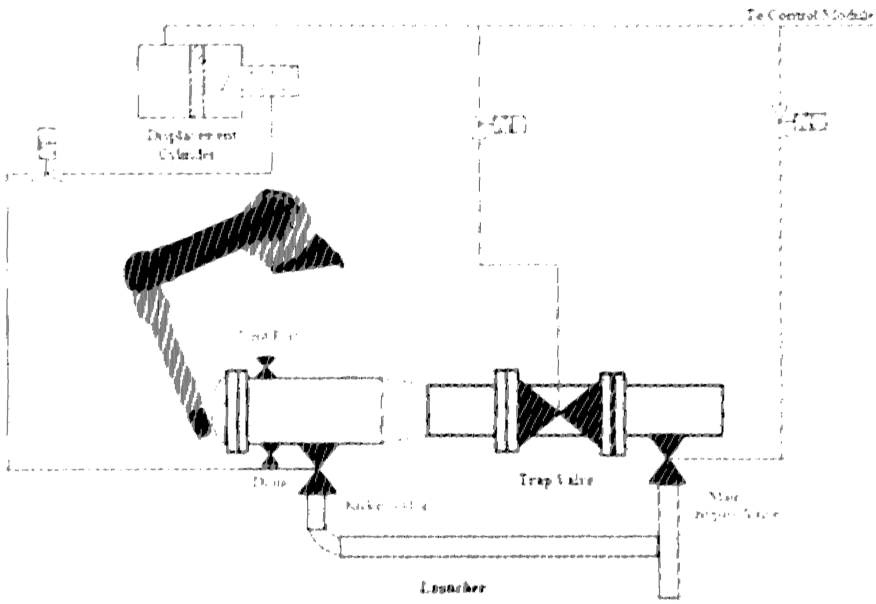


Figure 25: Stand Alone Robot Configuration with Automated Valve System

4.1.2 Rail guided robot configuration

In this configuration, ABB IRB5500 robotic arm is mounted on a rail which allows access to all valves and closure door. Robot will execute all tasks in pigging operation. Thus end effector of the robot design shall allow tool changing feature which are pig handling tool and valve manipulator tool.

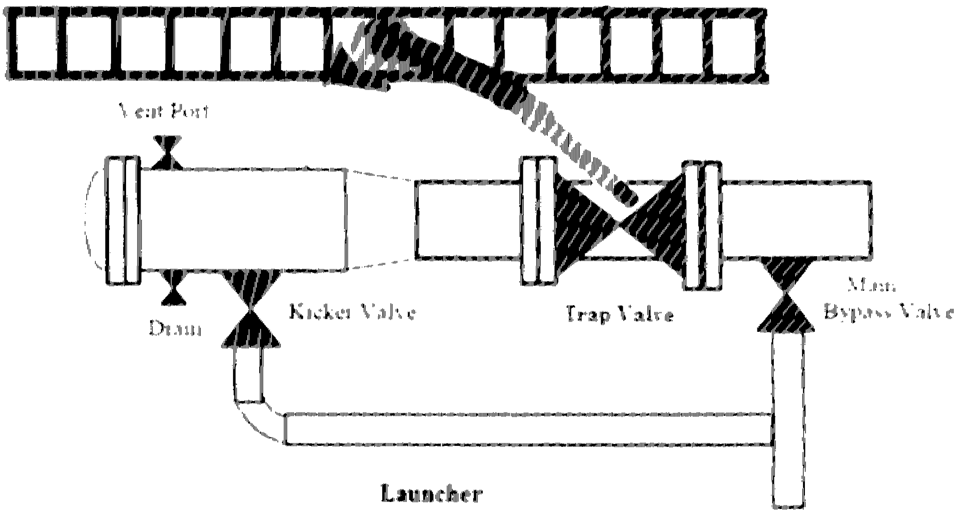


Figure 26: Rail Guided Robot Configuration

4.1.3 Multiple robot configuration

There will be more than one robotic arm to execute specific task. One robot will handle the pig while other will operate the valves.

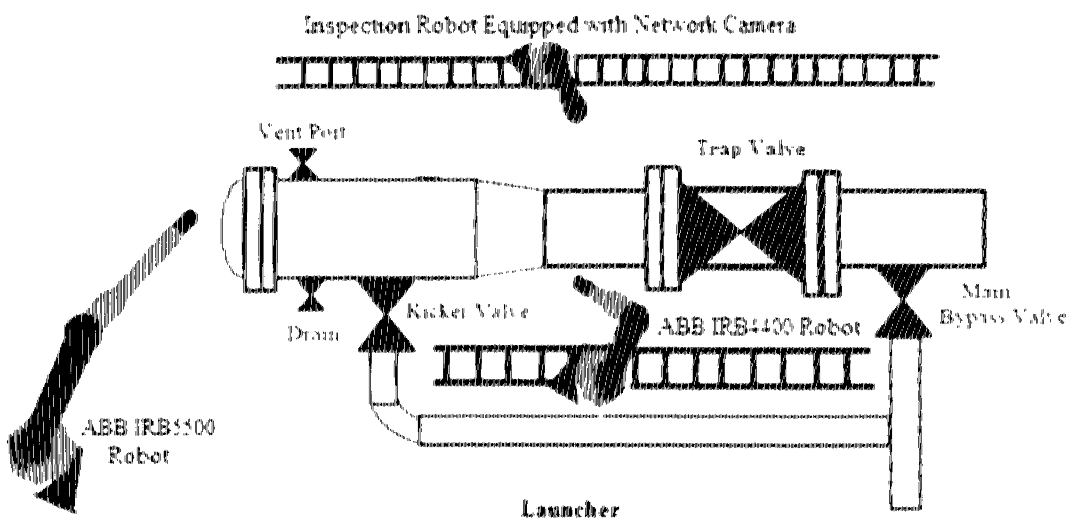


Figure 27: Multiple Robot Configuration

ABB IRB5500 robot is utilized for pig handling task. For valve operation task 2 collaborating robots are involve. The first is ABB IRB4400 (refer appendix 3) robot equipped with a specially designed tool for valve manipulation (see fig. 27 and fig. 28) and the second robot equipped with a standard network camera with resolution 640 by 480 pixels (Fig 29). The camera equipped "inspection robot" extracts the exact position and orientation of the valve and then send to the second robot (ABB IRB4400) which moves through a rail and manipulates the valve.

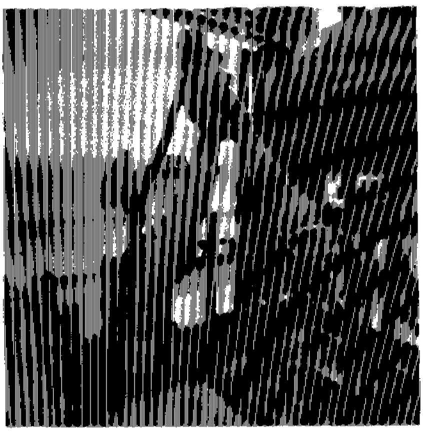


Fig 28: ABB IRB4400 Robot With Tool Charger and Manipulation Tool (David A. Anisi, 2010)

Fig 29: Valve Manipulation Tool (David A. Anisi, 2010)

Fig 30: Inspection Robot Equipped With a Network Camera (David A. Anisi, 2010)

Once the inspection robot has determined the position and orientation of the valve with sufficient level of accuracy and sent them to the second robot, it moves to a view-point providing the remote operator visual overview of the valve. The second robot then automatically picks up the associated valve manipulation tool and move towards the valve. A proximity switch is used in order to determine when the tool has reached appropriate horizontal level to allow safe turning of the valve. Upon completion, the valve manipulation tool is put back in the tool shed after which both robots return to their home positions.

4.2 CONTROL SYSTEM

Pig launcher robot is design to undertake tasks ranging from pig handling and performing valve operation. Regardless of the assigned task, the basic capability of a mobile robot is to move efficiently (along short rail trajectories) and safely (without collisions) during operation. Like any other robotic system, pig launcher robot must rely on on-line sensory information to take actions. Sensory information consists (M. I. SERRANO, 2006):

- proprioceptive (i.e., an odometry process that gives the robots coordinates based on internal encoders)
- exteroperception (i.e., information about the external environment).

Pig launcher robot mainly use three types of sensors to perceive their surroundings, namely:

- tactile sensors which inform about contacts (robot and the environment)
- range sensors (lasers, ultrasounds, or infrareds) which return distances after appropriate transformations
- vision which act as robot eyes

Human-made controllers are required because every possible situation the robot might face have to be anticipated especially during difficult task such as taking sample. Operator must tune the controller parameters to achieve efficient performance. An alternative is to provide remote control system for pig launcher robot which can be further separated into two parts:

- remote control for the traction system
- Trajectory control of the end-effector

The traction system is controlled by a remote joystick to drive the robot. The basic commands are forward, backward, rotating clockwise and anti-clockwise. It is more difficult to control the tracking of the end-effector, because of the robot arm complexity. Usually, traditional algorithms such as forward and backward kinematical, are implemented to calculate the tracking end-effector, due to the use of a joystick remote control. This algorithm control becomes more complex with incremental degrees of freedom. All these disadvantages have been overcome by the implementation of an exoskeleton as a remote control system, which allows more simplicity when operating (M. I. SERRANO, 2006) . This kind of interface allows the operator to control the arm robot more easily and spontaneously. Video camera mounted on the robot helps operator see the end-effector. Hence, the operator feels a sensation of virtual reality.

Angle sensors which located in the joints of the exoskeleton help in measuring the three dimensional position. Both the exoskeleton and joystick are connected to a micro-controller that is carried on the operator's body. This micro-controller sends the operator actual arm position and also the track system direction in real time mode to the robot. Figure 30 shows the arm correlation between the human arm and the exoskeleton control arm indicating; parts A (forearm) and B (upper arm) and their correlation.

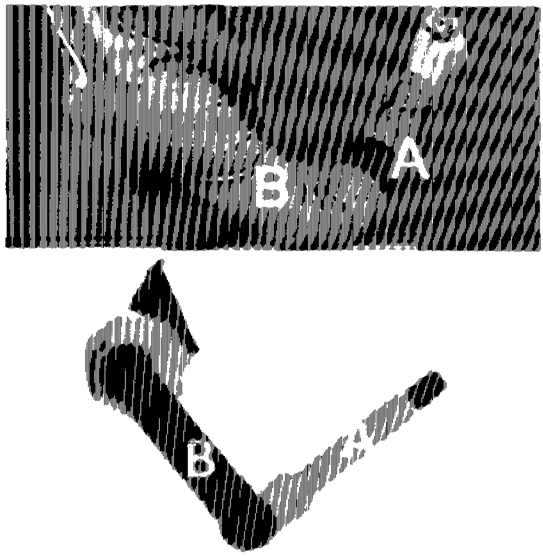


Fig 31: Correlation between human arm and exoskeleton control arm

4.3 COMMUNICATION SYSTEM

The communication system can be a wireless or cable, depending on the situation. Communication must be secure to ensure that the operator responds instantly to the commands. The communication system is physically prepared with two microcomputers, one located in the exoskeleton control and the other inside the robot. Wireless communication is based on high frequency radio communication because of the long range coverage. Electrical actuators are used to handle each joint and even the claw.

4.4 QUANTITATIVE ANALYSIS

In this study, the authors examined the applicability of the three conceptual ideas using workspace analysis. Workspace of all three conceptual robot configurations is generated using AutoCAD. This analysis is based on 2D model and top view has been chosen. The workspace of a robot is defined as the set of all end effector configurations which can be reached by some choice of joint coordinates. Workspace analysis is use to determine the maximum access of robotic arm to all equipment involve in pig launching operation such as vent valve, drain valve, kicker valve, trap valve, balance valve, main bypass valve, and closure door.

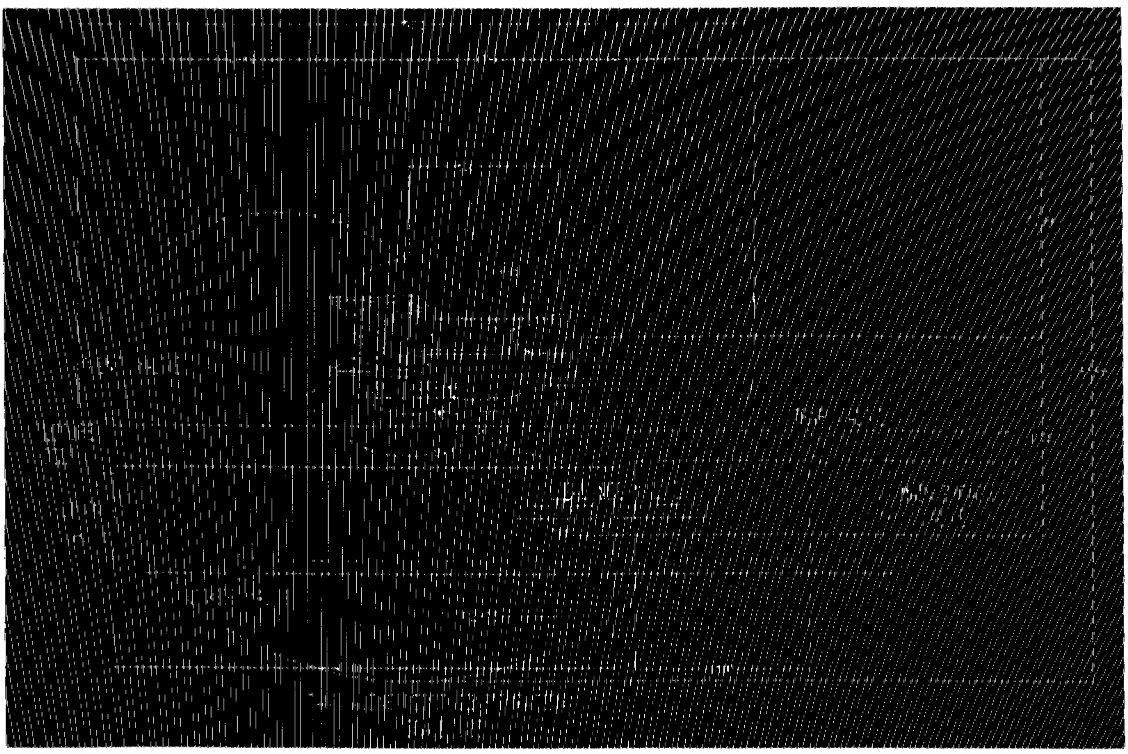


Fig 32: Stand Alone Robot Configuration Workspace

Red line envelope demonstrates the workspace of robot configuration. For stand alone robot configuration, robot arm is unable to access trap and main valve. Thus installation of automated valve system which has been implemented for subsea system and discuss in section 4.1.1 is required.

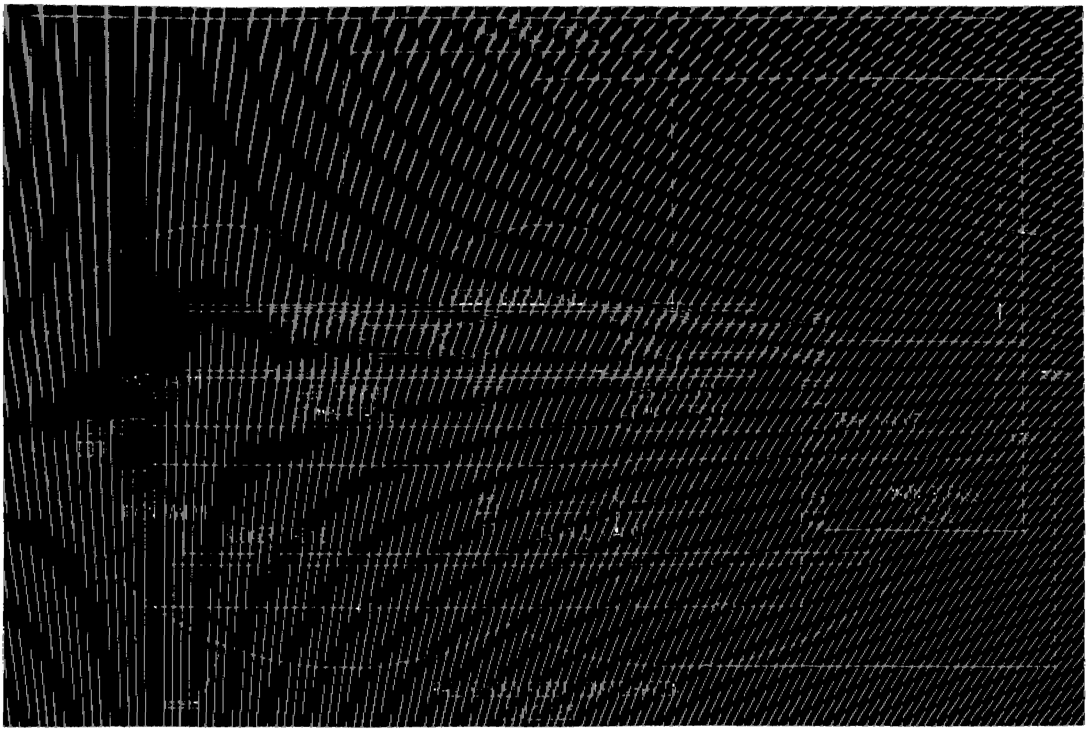


Fig 33: Rail Guided Robot Configuration Workspace

For rail guided configuration, robot arm is able to access all valve and closure for the 3 meter maximum rail stroke used.

Fig 34: Multiple robot configuration workspace

In multiple robot configuration, ABB IRB5500 robot able to access closure door for pig handling operation. Beside, IRB5500 shall handle vent and drain valve operation. ABB IRB4400 robot has access on kicker, balance, trap and main bypass valve for 3.5 meter rail stroke used.

4.5 QUALITATIVE ANALYSIS

In this study, the authors also examined the applicability of the three conceptual ideas using 'automation needs determination method' using Analytical Hierarchy Process (AHP). The AHP was developed by Saaty in the 1980' and has been utilized in broad application areas such as decision making, resource allocation, and optimization. A detailed description of the basic procedure involved in AHP is illustrated in Guo, S. & Tucker, R. (1993). Automation Needs Determination Using AHP Approach (Guo, 1993). For this study three automation concern factor (discuss in sec. 2.7) are emphasize which are safety, productivity and quality.

To achieve a weight for each factor shown in Table 3, a questionnaire shall be distributed to authors and experts of pigging operation. But due to time constrain and limited of information, wall painting robot AHP assessment weight (Young S. Kim, 2007) is taken as reference.

FACTOR	SAFETY	PRODUCTIVITY	QUALITY	ROW SUM	WEIGHT
SAFETY	1	1/4	1/3	0.36	12%
PRODUCTIVITY	4	1	3	1.82	61%
QUALITY	3	1/3	1	0.81	27%
COLUMN SUM	8	1.58	4.33	3.00	100%

1: Two factors contribute equally,
2: Slightly favor one factor over another,
3: Moderately favor one factor over another,
4: Strongly favor one factor over another,
5: One factor dominates another

Table 3: Assessment of Weights using AHP (Young S. Kim, 2007)

Automation concern index (ACI) (Guo, 1993) is then executed by comparing the factors (safety, productivity, and quality) in a matrix format. In this study, the sub factor for each design concern to be considered in developing the pig launcher robot were derived from the analysis results of the general and key technical considerations. Advantages and disadvantages of each conceptual idea are qualitatively described and the best alternative for pig launcher robot is then suggested.

Table 4 shows the estimated result of ACI for suggested each conceptual idea. To reach a final ACI index, a value of 'O' or 'X' are assigned in all the sub-factors for each design concern shown in Table 1 and the results are then summed to be the input for each specific design concern. Here, the value 'O' indicates that the alternative (e.g., stand alone configuration) is associated with the specific sub-factor and the value 'X' means the alternative is not associated with the sub-factor. For example, the stand alone configuration robot can reduce accident rates compared to conventional method, thus the value 'O' is assigned in the cell (S1, A1).

Factor		Sub-factor	A1	A2	A3
S	S_1	Can reduce the accident rates compared to the conventional method?	O	O	O
	S_2	Can eliminate tedious and dangerous working procedure of conventional method?	O	O	O
	S_3	Can have a quick respond during emergency?	X	X	O
	S_4	Can eliminate human intervention during pigging operation?	O	O	O
P	P_1	Can reduce pig launching operation time compared to conventional method?	O	O	O
	P_2	Have quick access or intervention with all components?	X	X	O
Q	Q_1	Can improve pig launching quality in term of precision of pig handling compared to conventional method?	O	O	O

Estimation Result of Automation Concern Index (ACI)				
Alternative	Safety	Productivity	Quality	ACI
A1	3	1	1	0.67
A2	3	1	1	0.67
A3	4	2	1	1.00

S: Safety, P: productivity, Q: Quality, A1: stand alone robot configuration, A2: rail guided robot configuration, A3: multiple robot configuration

Table 4: Automation Concern Index (ACI) for the Suggested Conceptual Ideas

ACI_{A1}= (0.12 x 3/4) + (0.61 x 1/2) + (0.27 x 1/1) = 0.67

ACI_{A2}= (0.12 x 3/4) + (0.61 x 1/2) + (0.27 x 1/1) = 0.67

ACI_{A3}= (0.12 x 4/4) + (0.61 x 2/2) + (0.27 x 1/1) = 1.00

4.6 SELECTION OF THE BEST ALTERNATIVE USING DECISION MATRIX

Decision matrix has been chosen by author as a decision making tool to select the best alternative. Four criteria have been emphasized and weighted for the matrix which are less complexity of the system, respond time, workspace and cost.

Complexity of the system emphasizes on the structure of a system. Author approach is closer to a dictionary definition of 'complicated'. A system is complicated when it is composed of many parts interconnected in intricate ways. Besides a complicated system sometimes need major changed on existing plant layout. A complicated system will result in difficulty of installation task and high level of maintenance and operation task.

Respond time related to the ability of system to execute pig launching operation based on time variable. Respond time basically related to how quick a system can intervention with equipment (valves and door) during operation and in case of emergency or unexpected event. For this study, respond time relatively determine based on logic time estimation for robot end effector to change tools and robot movement to target position during pig launching operation.

Workspace of the robot system defines as all the position/orientation that can be reached by the robot platform.

Robot Configuration	Less Complexity of the System	Respond Time	Workspace	Cost
Stand alone	Require major change on plant system to install automated valve controller system.	Higher respond time if automated valve system is installed because robot arm only handle pig loading task.	Workspace envelope of the robotic arm able to cover pig handling working area.	Cost is depend on: • Major change on existing pig launcher equipment such as valves • Major change on existing plant schematic to install automated valve control system • Utilisation of single robot arm • Power system for robot.
Rail guided	Require installation of rail and power system for the robot.	One robot arm need to handle all tasks and involve end effector tool changing operation.	Workspace envelope of the system able to cover working area.	Cost is depend on: • Utilisation of single robot with rail as a guided • Power system for robot
Multiple	Require installation of rail, 3 robot and power system.	Higher respond time. Each robot has own job specification and can work simultaneously.	Workspace envelope of the system able to cover working area.	Cost is depend on: • Utilisation of 3 robot with rail guided • Additional power system for robot

Table 5: Comparison for the Suggested Ideas

Robot Configuration	**Less Complexity of the System**		**High Respond Time**		**Workspace**		**Low Cost**		**TOTAL**
Weight	5		4		4		4		
	Rating	Score	Rating	Score	Rating	Score	Rating	Score	
Stand alone	3	15	5	20	3	12	3	12	59
Rail guided	5	25	3	12	4	16	5	20	73
Multiple	4	20	5	20	5	20	4	16	76

Weighted: 5 Very high importance, 4 High importance, 3 Medium importance, 2 Low importance, 1 Very low importance, 0 not important

Table 6: Assessment using Decision Matrix

Based on the analysis results; automation concern index, ACI (1.00) and decision matrix total score (76), multiple robot configuration is the best alternative compare to other model.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

The oil and gas industry is facing a number of challenges in the coming years, and these must be tackled by innovative and novel technical solutions. This paper presents the current status of our work towards realizing the next generation robotized oil and gas facilities. Future robotized oil and gas facilities represent a major opportunity in this context with the main goal of improved HSE, as well as production- and cost efficiency.

In this study, conceptual designs of the pig launcher robot and feasibility analysis model were proposed in an effort to automate pigging operation in oil and gas plant. This study also analyzed the conventional pig launching process for and its arising problems. Based on the general and key technical considerations required for automation of pig launching operation, the multiple robot configuration was selected as the best design alternative. Finally, it is anticipated that the conceptual design and the analysis model of the pig launcher robot presented in this study would be effectively used as a good benchmark in designing and analyzing other automated machines.

5.2 RECOMMENDATION

Nevertheless, although robotic systems can take over most of the repetitive, dangerous, heavy and dirty jobs, they can rarely do the entire job without involving people in the loop. This is partly due to the unpredictable and uncertain nature of the surrounding environment, which may include unforeseen tasks. Recognizing this paradigm, the robots are seen as assets in the control system which are used as the field operator's "eyes, ears and hands". Thus in future, advance technology can be applied to the robot system and autonomous pig launcher robot can be developed.

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APPENDICES

APPENDIX 1

UNITED STATES DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE
GULF OF MEXICO REGION

ACCIDENT INVESTIGATION REPORT

1. OCCURRED
   DATE: **23-OCT-2008** TIME: **1730** HOURS

2. OPERATOR: **Energy Resource Technology GOM, I**
   REPRESENTATIVE: **Wendy Braddock**
   TELEPHONE: **(281) 618-0551**
   CONTRACTOR:
   REPRESENTATIVE:
   TELEPHONE:

3. OPERATOR/CONTRACTOR REPRESENTATIVE/SUPERVISOR ON SITE AT TIME OF INCIDENT:

4. LEASE: **G02280**
   AREA: **SM** LATITUDE:
   BLOCK: **130** LONGITUDE:

5. PLATFORM: **A**
   RIG NAME:

6. ACTIVITY:
   - [ ] EXPLORATION(POE)
   - [x] DEVELOPMENT/PRODUCTION (DOCD/POD)

7. TYPE:
   - [ ] HISTORIC INJURY
     - [x] REQUIRED EVACUATION 1
     - [ ] LTA (1-3 days)
     - [ ] LTA (>3 days
     - [ ] RW/JT (1-3 days)
     - [ ] RW/JT (>3 days)
     - [ ] Other Injury
   - [ ] FATALITY
   - [ ] POLLUTION
   - [ ] FIRE
   - [ ] EXPLOSION
   - LWC
     - [ ] HISTORIC BLOWOUT
     - [ ] UNDERGROUND
     - [ ] SURFACE
     - [ ] DEVERTER
     - [ ] SURFACE EQUIPMENT FAILURE OR PROCEDURES
   - COLLISION [ ] HISTORIC [ ] >$25K [ ] <=$25K
   - [ ] STRUCTURAL DAMAGE
   - [ ] CRANE
   - [ ] OTHER LIFTING DEVICE
   - [ ] DAMAGED/DISABLED SAFETY SYS.
   - [ ] INCIDENT >$25K
   - [ ] H2S/15MIN./20PPM
   - [ ] REQUIRED MUSTER
   - [ ] SHUTDOWN FROM GAS RELEASE
   - [x] OTHER **Injury to person**

6. OPERATION:
   - [x] PRODUCTION
   - [ ] DRILLING
   - [ ] WORKOVER
   - [ ] COMPLETION
   - [ ] HELICOPTER
   - [ ] MOTOR VESSEL
   - [ ] PIPELINE SEGMENT NO.
   - [x] OTHER **Pigging Operation**

8. CAUSE:
   - [x] EQUIPMENT FAILURE
   - [x] HUMAN ERROR
   - [ ] EXTERNAL DAMAGE
   - [ ] SLIP/TRIP/FALL
   - [ ] WEATHER RELATED
   - [x] LEAK
   - [ ] UPSET H2O TREATING
   - [ ] OVERBOARD DRILLING FLUID
   - [ ] OTHER ______

9. WATER DEPTH: **215** FT.

10. DISTANCE FROM SHORE: **82** MI.

11. WIND DIRECTION:
    SPEED: M.P.H.

12. CURRENT DIRECTION:
    SPEED: M.P.H.

13. SEA STATE: FT.

MMS - FORM 2010 PAGE: 1 OF 5
EV2010R 12-JUN-2009

17. DESCRIBE IN SEQUENCE HOW ACCIDENT HAPPENED:

On October 23, 2008, at approximately 1730 hrs, a Lead Operator (LO) sustained a break to his right arm just above his wrist during a pipeline pigging operation. All valves leading to the pig launcher were closed/isolated, and the pig launcher was depressurized in preparation for the pig's insertion. Subsequent to loading the pig into the launcher/receiver, the pig prematurely ejected backwards striking the LO on his right arm before he could remove his arm and securely close the trap door cover. The LO was evacuated by helicopter and flown to the Houma Terrebonne General Hospital for treatment. The LO was released to restricted work duty until November 10, 2008.

18. LIST THE PROBABLE CAUSE(S) OF ACCIDENT:

Pipeline system pressure slowly leaked through two closed main 8" manual isolation block valves located on the vertical run of the pig launcher. This allowed pressure to build up inside the launching/receiving trap behind the pig once it was placed in the launcher. The pig, being new, allowed for a complete seal with no blow-by. After initially bleeding down the pig launcher system, the LO failed to ensure the pig launcher remained depressurized while being isolated from all pressure sources.

19. LIST THE CONTRIBUTING CAUSE(S) OF ACCIDENT:

Although a Job Safety Analysis (JSA) was conducted prior to the operation, the LO failed to follow the JSA guidelines secondary to the LO's upper body and right arm being exposed to pig loading operation. This bodily exposure violated the JSA recommended procedure, as well as the ERT pig launching procedure, of not standing in front of the launcher/receiver during pigging operations.

20. LIST THE ADDITIONAL INFORMATION:

MMS recommends the following:

*Pig launching Standards of Operating Procedures (SOPs) should be discussed during the JSA, and followed by all personnel during the pig launching operation.

*All safety precautions and procedures should be followed while performing pig launching operations on the depressurized/pressurized piece of equipment. As per the ERT pig launching procedures, a wooden pig loading pole or rod should be used to safely insert the pig into the launcher to prevent unnecessary personnel exposure.

*Contingency procedures, including Stop Work Authority (SWA), should be in place to deal with faulty or inadequate safety systems or devices; e.g., leaking block valves and/or insufficient venting.

21. PROPERTY DAMAGED:

None

NATURE OF DAMAGE:

None

ESTIMATED AMOUNT (TOTAL):

22. RECOMMENDATIONS TO PREVENT RECURRANCE NARRATIVE:

The MMS Lafayette District has no recommendations to the MMS Region Office of Safety Management (OSM).

23. POSSIBLE OCS VIOLATIONS RELATED TO ACCIDENT: **YES**

24. SPECIFY VIOLATIONS DIRECTLY OR INDIRECTLY CONTRIBUTING. NARRATIVE:

Incident of Noncompliance (INC) G-110 is issued "After the Fact" to document that Energy Resource Technology GOM (ERT) failed to protect health, safety, and the environment by not performing operations in a safe and workmanlike manner as follows:

ERT failed to ensure personnel follow all written procedures including the JSA and SOP recommendations. Specifically, the LO failed to ensure that the pig launcher sustained a zero pressure prior to loading the pig into the launcher. In addition, the LO failed to stay clear of the pig launcher while inserting the pig.

ERT is advised to submit a letter of explanation to the Lafayette District Manager addressing the above INC, and ERT's plans for eliminating future incidents of this nature.

25. DATE OF ONSITE INVESTIGATION:

27-OCT-2008

26. ONSITE TEAM MEMBERS:

Douglas Frerich / Mark Shuff / Jason Abshire /

29. ACCIDENT INVESTIGATION PANEL FORMED: **NO**

OCS REPORT:

30. DISTRICT SUPERVISOR:

Elliott S Smith

APPROVED

DATE: 22-DEC-2008

INJURY/FATALITY/WITNESS ATTACHMENT

☐ OPERATOR REPRESENTATIVE ☐ INJURY

☐ CONTRACTOR REPRESENTATIVE ☐ FATALITY

☒ OTHER ____________________ ☒ WITNESS

NAME:

HOME ADDRESS:

CITY: STATE:

WORK PHONE: TOTAL OFFSHORE EXPERIENCE: YEARS

EMPLOYED BY:

BUSINESS ADDRESS:

CITY: STATE:

ZIP CODE:

APPENDIX 2

National Energy Board | Office national de l'énergie

File: OF-SURV-INC 02
25 April 2007

To: All companies under National Energy Board jurisdiction
Canadian Energy Pipeline Association
Canadian Association of Petroleum Producers, and
Provincial Regulators

National Energy Board Safety Advisory
NEB SA 2007-01

Attached is a safety advisory regarding the hazards associated with pipeline pigging activities. The Board expects that this advisory be given wide circulation to personnel involved in maintenance and pipeline operations within your organization.

If you have questions concerning this initiative, please call Karen Duckworth at (403) 299-3669 or Glenn Cameron at (403) 299-3624.

Yours truly,

David Young
Acting Secretary

Attachment

444 Seventh Avenue SW
Calgary, Alberta T2P 0X8

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Canada

Telephone/Téléphone : 403-292-4800
Facsimile/Télécopieur : 403-292-5503
http://www.neb-one.gc.ca
Telephone/Téléphone : 1-800-899-1265
Facsimile/Télécopieur : 1-877-288-8803

National Energy Board | Office national de l'énergie

Safety Advisory

NEB 2007-01

25 April 2007

Pipeline Pigging Operations: Open to Injury

Incident Description

At approximately 5:15 p.m. on November 23, 2006, during planned work related to an internal inspection project, two batch pigs were ejected under pressure from the barrel of a 14" temporary receiving trap striking and seriously injuring two workers. A contractor on site witnessed the incident and experienced symptoms of shock.

This is the eighth NEB reported pipeline pigging related injury incident since 1962. The Board is concerned as it notes that regulators are typically only aware of those pigging incidents that seriously injure or kill, since near misses are normally not reported. Prevention, awareness, personnel training and appropriate pig trap design are key!

Factors Contributing to Pipeline Pigging Incidents

- Design of receiving trap
- Method or tools used for extracting lodged pigs
- Pressure expansion of trapped gas behind sealed pig
- Leaking valves
- Plugged vents
- Hydrate formation
- Lack of training or complacency
- Lack of hazard awareness
- False sense of security and reliance only on pressure gauges
- Sour gas trapped in pig cups

Preventive Actions

- Management review of existing facility design and design specifications
- Technical analysis which considers pigging parameters such as product, operational function, constraints, pig train length and clearance between the pig and the trap inside diameter
- Hazard identification and risk assessment including management of changes
- Awareness, training and competencies of personnel
- Procedures that address normal and upset conditions

"STAY OUT OF THE PIG'S LINE OF FIRE"

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APPENDIX 3

Robotics

IRB 4400 Industrial Robot

Main applications

An extremely fast, compact robot for medium to heavy handling. Exceptional all-round capabilities make it suitable for a variety of manufacturing applications. The load capacity of 60 kg at very high speeds usually permits handling of two parts at a time. A rigid, well-balanced design and patented TrueMove™ function provide smooth and fast movement throughout the entire working range.
This ensures very high quality in applications such as cutting. Rapid maneuverability makes the IRB 4400 perfectly matched for applications where speed and flexibility are important. The compact design and protected versions enables use in situations where conventional robots cannot work, such as foundry and spraying applications. The foundry plus version is IP 67 protected and can be washed with high pressure steam, which makes it ideal for use in harsh environments.

The robust, rigid construction means long intervals between routine maintenance. Well-balanced steel arms with double bearing joints, a torque-strut on axis 2 and use of maintenance-free gearboxes and cabling also contribute to the very high levels of reliability. The drive train is optimised to give high torque with the lowest power consumption for economic operation.

The extensive communication capabilities include serial links, network interfaces, PLC, remote I/O and field bus interfaces. This makes for easy integration in small manufacturing stations as well as large scale factory automation systems.

Power and productivity
for a better world™

ABB

IRB 4400

Robot versions	Reach	Payload	Standard	Foundry Plus 2	Foundry Prime 2
IRB 4400/60	1.96 m	60 kg	x	x	x
Supplementary load					
on axis 1		35 kg			
on axis 3		15 kg			
on axis 4		5 kg			
Number of axes					
Robot manipulator		6			
External devices		6			
Integrated signal supply		23 signals and 12 power on upper arm			
Integrated air supply		Max. 8 bar on upper arm			
IRC5 Controller variants		Single cabinet, Dual cabinet			

Position repeatability	0.19 mm
Path repeatability at 1.6 m/s	0.56 mm

Working range

Axis	Working range	Maximum speed
1, C Rotation	Axis 1 +165 to -165	Axis 1 150°/s
2, B Arm	Axis 2 +95 to -70	Axis 2 120°/s
3, A Arm	Axis 3 +65 to -60	Axis 3 120°/s
4, D Wrist	Axis 4 +200 to -200	Axis 4 225°/s
4, Option	Unlimited	
5, E Bend	Axis 5 +120 to -120	Axis 5 250°/s
6, P Turn	Axis 6 +400 to -400	Axis 6 330°/s
6, Option	Unlimited	

Supply voltage	200-600 V, 50/60 Hz
Rated power	
Transformer rating	7.8 kVA

Robot mounting	
IRB 4400	Floor
Dimensions	
Robot base	920 x 640 mm
Weight	
Robot	1040 kg

Ambient temperature	
Manipulator	5 - 45°C
Relative humidity	Max. 95%
Degree of protection	
Standard version	IP 54
Foundry Plus 2 and Foundry Prime 2	IP 67 and high pressure steam washable
Noise level	Max. 70 dB (A)
Safety	Double circuits with supervision, emergency stops and safety functions, 3-position enable device
Emission	EMC/EMI-shielded

Data and dimensions may be changed without notice

IRB 4400 60